

Detection of Both Voice and Tones Using Goertzel Filters

Technical Field

This invention relates generally to call classification and call-
5 progress monitoring.

Background of the Invention

Call classification, also referred to as call-progress monitoring, is the term applied to determining what type of signals are present on a
10 communications link. Generally, call classification needs to distinguish between noise, silence, voice (including other audio, such as music and announcements), and control signals (e.g., control tones), and to identify the particular control signals.

Various algorithms are commonly used for voice detection,
15 such as peak-signal detection, rate-of-change of zero crossings, and auto-correlation. They tend to not be very accurate in distinguishing voice from other sounds, such as noise. For example, existing algorithms often mis-detect clicks and pops produced by analog phone lines as voice. Also, many existing algorithms take a long time to identify presence of voice
20 signals. But time is very critical in call processing, which requires substantially "real-time" call classification.

The use of Goertzel filters is known for control-tone detection and identification (see, e.g., U.S. patent numbers 5,521,967 and 6,370,244, and the predictive call dialer from Avaya Inc. (formerly Mosaix
25 Inc.), Redmond, Washington, USA). A Goertzel filter is an implementation of a Discrete Fourier Transform as a digital filter that is structured to reduce the number of computations required to compute the transform. It also requires minimal signal buffering because each signal sample is processed when received (i.e., substantially in "real-time" with only a small

delay). However, call classifiers have not employed Goertzel filters for voice (audio) detection. For example, while U.S. patent number 5,521,967 employs Goertzel filters for tone detection and identification, it employs a low-pass filter for voice detection. Since the low-pass filter allows both
5 voice and noise signals to pass, the detector is susceptible to mis-identifying high noise levels as voice.

Summary of the Invention

This invention is directed to solving these and other problems
10 and disadvantages of the prior art. Generally according to the invention, Goertzel filters are used to detect presence of voice (including other audio signals, such as music) and to distinguish it from noise and control signals on a communications link. According to the invention, a voice detector comprises a plurality of Goertzel filters each operating at a different
15 frequency within the voice range. Some of the filters operate at frequencies the same as those of control signals and others of the filters operate at frequencies other than those of the control signals. Each of the filters receives a signal to be analyzed for presence of voice and detects energy of the received signal at substantially one (the center of the notch)
20 frequency of that filter. The voice detector further comprises a comparator connected to the filters, that compares the energies detected by the filters against thresholds. The comparator responds to at least three of the filters simultaneously detecting energy above a noise threshold and below a control signal threshold by indicating that the signal comprises voice.
25 Illustratively acting as a call classifier, the comparator responds to a filter operating at a frequency of a control signal detecting energy above a control signal threshold by indicating that the analyzed signal comprises that control signal. Noise or silence is indicated when the total signal energy falls below a noise threshold.

Also according to the invention, a method of detecting voice in a signal to be analyzed comprises the operation of the Goertzel filters and the comparator as characterized above.

Compared to other means of voice detection, voice detection
5 effected according to the invention is more accurate and faster. This is because voice detection effected according to the invention is based upon frequency information instead of empirical (heuristic) analysis and because it is not prone to confusion by line clicks and pops or other noise. It is also computationally efficient because it computes the signal energy
10 at each frequency of interest only once, and then merely reuses this computed value in comparisons against different thresholds to determine what that energy represents.

Brief Description of the Drawing

15 These and other features and advantages of the invention will become more apparent from the following description of an illustrative embodiment of the invention considered together with the drawing in which:

Fig. 1 is a graph of the frequencies and energy levels of voice
20 and control signals in an illustrative communications link;

Fig. 2(a) and 2(b) are a flowchart of logic of voice and control signal detection according to the invention for the graph of Fig. 1;

Fig. 3 is a block diagram of a call classifier that implements an illustrative embodiment of the invention;

25 Fig. 4 is a block diagram of a data entity of a comparator and combiner of the call classifier of Fig. 3;

Fig. 5 is a flow diagram of the operation of the comparator and combiner of the call classifier of Fig. 3; and

Fig. 6 is an illustration of target-signal windows created by a
30 sampling and windowing function of the call classifier of Fig. 3.

Detailed Description

Fig. 1 shows the spectrum of signals that a call classifier typically must deal with. Call progress tones (CPTs), such as ringing, dial-tone, busy tone, reorder tone, etc., are typically located in the frequency
5 range of 300-800 Hz. Special information tones (SITs), such as tones that precede network announcements, are typically located in the frequency ranges of 850-1050 Hz, 1300-1450 Hz, and 1700-1850 Hz. Modem tones (MTs), such as modem or fax answer acknowledgment, are typically located in the frequency range of 2000-2300 Hz. Voice signals mostly
10 occupy the frequency range of about 0-4500 Hz, and are normally concentrated in the narrowband-voice-frequency range of 300-3300 Hz. Noise can occur at any and all frequencies.

Because CPTs are dual-frequency signals, signal energy is concentrated at two frequencies for each CPT. For each SIT and MT,
15 energy is concentrated at one frequency, as they are single-frequency signals. In contrast, voice-signal energy is spread over the entire frequency range. Although the higher frequencies have less importance in speech than the lower frequencies, the average voice energy is generally spread over the entire spectrum. Hence, if a call classifier sees a high
20 energy concentration at only one or two frequencies, then the signal is deemed to be of type "control signal" (i.e., "tone") and not "voice," because "voice" has substantially equal distribution of energy over a large number of frequencies.

According to the invention, therefore, a plurality of Goertzel
25 filters, with frequencies **10** spaced over the entire voice spectrum as shown in Fig. 1, is used for call classification. Within the control signal (CPT, SIT, and MT) bands, a Goertzel filter is centered at each control-signal frequency. Goertzel filters centered at additional frequencies within the control signal bands may also be used. Additional Goertzel filters are
30 used at frequencies outside of the control signal bands within the voice band. Illustratively, Goertzel filters having frequencies **10** spaced about

every 100 Hz throughout the voice band are employed. However, the Goertzel filters need not be spaced equally across the entire spectrum, but may be more concentrated in sub-spectra of most interest, i.e., in the CPT, SIT and MT bands. Also, minimum Goertzel filter frequency spacing
 5 is inversely proportional to signal sample window size, to ensure that the Goertzel filters' notch (detection) spectra do not overlap.

A Goertzel filter detects presence of a signal at its corresponding (notch center) frequency if it detects energy at that frequency that relates to a threshold energy level in a predetermined way
 10 (e.g., exceeds the threshold). The threshold energy level may be expressed as a ratio of the energy detected at the corresponding frequency and the total signal energy .

It has been empirically determined that if a Goertzel filter within the SIT or MT frequency bands detects a concentration $T_{S,M}$ of about 60%
 15 or more of the total detected signal energy, then a SIT or an MT control signal has been detected; if a pair of Goertzel filters within the CPT frequency band each detects a concentration T_C of about 50% of the total energy, then a CPT control signal has been detected; and if a minimum predetermined number (>2) of Goertzel filters each detects an energy
 20 above a predetermined threshold, then voice has been detected. The predetermined number is determined empirically, based upon the application. The predetermined number of filters varies inversely with the magnitude of the threshold, and the magnitude of the threshold varies directly with the size of the signal sample window. For example, if each of
 25 at least three Goertzel filters detects a concentration T_V of between about 10% (T_{VMIN}) and 20% (T_{VMAX}) of the total energy of a 15 msec. signal sample window, then voice has been detected. Moreover, if the total detected energy is less than a certain threshold T_N , then either noise or silence has been detected. T_N is illustratively in the range of 1.2% to 3%.
 30 The upper limit for values that may be selected as T_{VMAX} is T_C in the CPT

band and $T_{S,M}$ in the SIT and MT bands; the lower limit for values that may be selected as T_{VMIN} is T_N .

The logic of this call classification is diagrammed in Fig. 2. The energies at the Goertzel filters' frequencies as well as the total signal
 5 energy are determined in a signal sample window, at step **200**. If the total detected signal energy is below the noise threshold of T_N , as determined at step **202**, detection of silence or noise is indicated, at step **226**. If the total energy is not below T_N , then the Goertzel filters in the SIT and MT frequency bands that detected energy whose ratio with the total energy is
 10 above the $T_{S,M}$ threshold are identified, at step **204**, the Goertzel filters in the CPT frequency band that detected energy whose ratio with the total energy is above the T_C threshold are identified, at step **206**, and the Goertzel filters in the voice frequency band that detected energy whose ratio with the total energy is between the T_{VMIN} and T_{VMAX} threshold are
 15 identified, at step **208**. Alternatively, instead of comparing the ratios against thresholds, the detected energies could have been directly compared against thresholds at steps **204-208** if the amplitude of signals, voice, and noise stays substantially constant over time. If exactly one Goertzel filter in the SIT and MT frequency bands detected energy whose
 20 ratio with the total energy is above the $T_{S,M}$ threshold, as determined at step **210**, and that filter's notch center frequency corresponds to a SIT or an MT signal frequency, as determined at step **212**, detection of that SIT or MT signal is indicated, at step **214**. Additionally, if exactly two Goertzel filters in the CPT frequency band detected energy whose ratio with the
 25 total energy is above the T_C threshold, as determined at step **216**, and those filters' frequencies correspond to the two frequencies of a CPT signal, as determined at step **218**, detection of that CPT signal is indicated, at step **220**. Additionally, if three or more Goertzel filters detected energy whose ratio with the total energy is between the T_{VMIN}
 30 and T_{VMAX} thresholds, as determined at step **222**, detection of voice is

indicated, at step **224**. The process is then repeated for the next signal sample window.

The configuration of a call classifier **300** that embodies an illustrative implementation of the invention is shown in Fig. 3. Call classifier **300** is connected to an input **302** of the target signals that are to be classified. A sampling and windowing function **304** takes samples (determines values) at different points in time of the amplitude (energy) of the target signal stream, and groups pluralities of successive samples into groups that represent segments, or windows, of the target signal stream. Function **304** then supplies the samples to a total energy function **305** and to a plurality of Goertzel filters **306-310**.

In one implementation, each second of the target signal stream is broken up by function **304** into **360** windows that are sampled at an 8kHz rate. Each window is 15 msec. long. Illustratively, function **304** performs a zeroth-order Discrete Spheroidal Sequences (DPSS) windowing function with a bandwidth of 50 Hz on 15 msec. (120 samples) of input signal. The starting times of consecutive windows are 5 msec. apart; consequently, every three consecutive windows partially overlap each other. This produces a sliding window as shown in Fig. 6. Overlapping windows are preferred because they produce higher detection accuracy than non-overlapping sequential windows. Also preferably, tapered windows (attenuated at the beginning and at the end) are used, in order to diminish the frequency-domain spikes caused by the turning on and turning off of rectangular windows.

Function **305** determines a total signal energy value E_T for each window. E_T is the square of the total energy in the window, and is computed as $E_T = \sum x_j^2, j=1, \dots, P$, where P is the number of samples in each window and x is the amplitude (energy) of an individual sample.

Goertzel filters **306-310** determine the signal energy value in each window at each Goertzel filter's respective frequency. Each energy

value is the square of the signal amplitude (energy) at that frequency. The plurality of Goertzel filters **306-310** may comprise a plurality of physically-distinct Goertzel filters. Or, the plurality of Goertzel filters may be virtual filters that are implemented via a single tuneable Goertzel filter that is

5 time-shared by the plurality of virtual Goertzel filters. Such a tuneable time-shared Goertzel filter may be implemented in firmware via a digital signal processor (DSP), in hardware via a field-programmable gate array (FPGA), or via software running on a computer.

The outputs of total energy detector **305** and of Goertzel filters

10 **306-310** are supplied to a comparator **312** that makes a determination therefrom of what has been detected and indicates the determination at an output **314**. In one embodiment, comparator **312** looks for consistent detection by a Goertzel filter in three out of five consecutive windows. That is, if in three out of five consecutive windows the Goertzel filter

15 detects energy having the same relationship to a signal's threshold(s), then that signal is deemed to have been detected. Comparator **312** may also be implemented in hardware, firmware, and/or software. Its functionality is shown in Figs. 4-5.

As shown in Fig. 4, each Goertzel filter **306-310** has associated

20 therewith its own data structure, state machine, or other entity **406-410**, respectively that represents a plurality of entries or tallies **422-426**. Each tally **422-426** corresponds to a different threshold $T_{S,M}$, T_C , and T_V , respectively, of Fig. 1, and comprises five flags **430-438** that are addressed in a round-robin fashion. Flags **430-438** correspond to the

25 current and the past four windows analyzed by the corresponding Goertzel filter, and flags **430-438** of each tally **422-426** indicate those of the five latest windows whose detected energy matched the tally's corresponding threshold.

Turning to Fig. 5, the procedure shown here is performed by

30 comparator and combiner **312** for each window, i.e., every 5 msecs. for the overlapping windows described above. Upon each start of the

procedure, at step 500, element 312 clears the oldest flag 430-438 of each tally 422-426 of each Goertzel filter's data entity 406-410, at step 502. The cleared oldest flag of each tally 422-426 now becomes the current flag. Element 312 receives from each Goertzel filter 306-310 the energy level detected by that filter during the current window, at step 504, and it combines those energy levels to determine the total energy level E_t of the current window, at step 506. Element 312 then checks whether the total detected energy level is exceeded by the noise energy level T_N , at step 508. If so, element 312 proceeds to step 544; if not, element 312 proceeds to step 510. At step 510, element 312 determines the ratio of the detected energy level and the total detected energy of the current window for each Goertzel filter 306-310. Element 312 then sets the current one of the flags 430-438 of tally 422 of each Goertzel filter 306-310 whose energy ratio exceeds the energy threshold $T_{S,M}$, at step 512, sets the current one of the flags 430-438 of tally 424 of each Goertzel filter 306-310 whose energy ratio exceeds the energy threshold T_C but does not exceed the energy threshold $T_{S,M}$, at step 514, and sets the current one of the flags 430-438 of tally 426 of each Goertzel filter 306-310 whose energy ratio exceeds the energy threshold T_{VMIN} but does not exceed the energy threshold T_{VMAX} , at step 516.

Element 312 then checks if any Goertzel filter 306-310 has at least three flags 430-438 of its $T_{S,M}$ tally 422 set, at step 520. If so, for each of the Goertzel filters 306-310 that has at least three flags 430-438 of tally 422 set, element 312 checks whether that Goertzel filter's frequency matches the frequency of an SIT or MT control signal, at step 522, and if so, indicates that the corresponding SIT or MT signal has been detected, at step 524. Element 312 next checks if any two Goertzel filters 306-310 have at least three flags 430-438 of their T_C tallies 424 set, at step 530. If so, for each pair of the Goertzel filters 306-310 that have at least three flags 430-438 of tally 424 set, element 312 checks whether the frequencies of the Goertzel filter pair match the frequencies of an CPT

control signal, at step 532, and if so, indicates that the corresponding CPT signal has been detected, at step 534. Next, element 312 checks in any three Goertzel filters 306-310 have at least three flags 430-438 of their T_v tallies 426 set, at step 540. If so, element 312 indicates that voice has
5 been detected, at step 542; if not, element 312 indicates that noise or silence has been detected, at step 544. Element 312 then ends the procedure for the current window, at step 550.

Of course, various changes and modifications to the illustrative embodiment described above will be apparent to those skilled in the art.
10 For example larger numbers of windows could be checked to make a determination. Also, larger numbers of set flags could be used to confirm a determination (e.g., to confirm detection of voice). Also, the invention can be used to distinguish voice from other types of sounds. Such changes and modifications can be made without departing from the spirit
15 and the scope of the invention and without diminishing its attendant advantages. It is therefore intended that such changes and modifications be covered by the following claims except insofar as limited by the prior art.